Adaptive Polarization Processing for Improved Detection/Classification of Stationary Targets

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Abstract— **A new technique for detection of stationary or slow-moving over-resolved targets on the ground, based upon a Hotelling T-squared test/generalized inner product (GIP) approach to signal analysis is presented. This robust detector separates radar returns from interference via a coherent process. This GIP-based processing can be applied to single-receiver channel systems, multiple spatial channel systems, multiple polarization channel systems or systems with multiple spatial and polarization channels.**

I. INTRODUCTION

Traditionally, stationary targets (on the ground, above the ground, and below the ground) can only be detected by a moving platform radar (airborne, space-based radar, for example) if their returns sufficiently exceed those from clutter (the ground) [1 – 7]. This requires that the radar cross-section exceeds that of the competing clutter patch established by the range and cross-range resolutions of the radar. To recognize an extended target via post detection processing requires the signal to interference plus noise ratio (SINR) be high enough in many resolution cells. Of course, both the object and clutter patch may be resolved using wide bandwidth SAR processing. This results in an image where some of the returns from resolved components of the doubly spread target may exceed those of their respective clutter patch. Historically, an image is formed and a target present declaration (alternate hypothesis) is made by an analyst via a non-coherent, albeit cognitive, process. There is no guarantee that these multiple detections in clutter processes are uniformly optimum. Even more important is the fact that these processes require a man-in-the-loop that causes significant delays in the availability of the declarations, and thus requiring significant communication assets.

A technique has been developed to significantly improve the detection of these targets in clutter [7]. This technique is based upon a generalized inner product (GIP) approach to dual-polarization data analysis. A single polarization version is discussed in [7]. The GIP has been previously applied in signal processing to improve the performance of adaptive radars operating in non-homogeneous clutter [8-10]. In this paper, the GIP-based processing is used to coherently combine the multiple returns from the doubly spread (range, Doppler) targets and to adaptively reject interference. Thus the subject method improves the probability of detecting the presence (or absence) of a spread target while at the same time it improves the estimation of target parameters. The improvement of the coherent GIP processing over incoherent SAR processing is a function of the ratio (RT) of the extended target compared with a representative resolution cell. The target signal increases by RT^2, noise by RT. Clutter residual after adaptive processing is a complex function of homogeneity statistics; inhomogeneous clutter add like noise but is not cancelled by the adaptive process; homogeneous clutter adds like a target but is cancelled almost completely by the adaptive process. Comparing the GIP process to the SAR process, we will have the signal-to-noise ratio (SNR) and signal-to-clutter ratio (SCR):

$$SNR_{GIP} = RT * SNR_{SAR}$$

$$SCR_{GIP} > RT * SCR_{SAR}.$$

The key to GIP-based parameter estimation is to maximize the over-resolved target power while suppressing clutter. Therefore, range-Doppler profiles (indices) of targets with different orientations and different locations are required. For this purpose, a database of target templates, including shape (structure of each target of interest), could be employed. If the shape and size of a target is approximately known, a corresponding target template could be used. The technique can be applied to one-dimensional objects (straight and bent wires), two-dimensional objects and three-dimensional objects. As an example we consider a thin wire in a circular shape.

Polarization diversity provides an additional degree of freedom in the interference rejection process but more importantly also provides data for the classification process. GIP based discrimination requires an approximate template of the potential target. Fidelity of the detector/classifier is greatly improved by polarization information.

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14. ABSTRACT
A new technique for detection of stationary or slowmoving over-resolved targets on the ground, based upon a Hotelling T-squared test/generalized inner product (GIP) approach to signal analysis is presented. This robust detector separates radar returns from interference via a coherent process. This GIP-based processing can be applied to singlereceiver channel systems, multiple spatial channel systems multiple polarization channel systems or systems with multiple spatial and polarization channels.

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II. DUAL POLARIZATION SIMULATION

A. Scenario and Coordinate System

The objective is to simulate the radar signals for airborne high-range resolution radar. The target is assumed to be a circular shape object on the ground. Figure 1 shows the scenario and the coordinate system. Further assume the object is made of thin conductive wire. We divide the object into many small segments. Each segment is short enough so that it can be approximated as a circular cylinder. The received signal is the coherent summation of returns from all the segments.

B. Polarization Scattering Matrix

The incident field at the target (here, a short segment of wire) can be resolved into two components of electric field E_0^H and E_0^V along the H and V axes, respectively. While the axes are arbitrary, we use the conventional horizontal H and vertical V axes (H or V polarization) in this paper. Similarly, the two components of scattered electric field along the H and V axes can be denoted as E_s^H and E_s^V, respectively. In general, the scattered electric field can be expressed in terms of the scattering matrix:

$$\begin{pmatrix} E_s^H \\ E_s^V \end{pmatrix} = \begin{pmatrix} a_{HH} & a_{HV} \\ a_{VH} & a_{VV} \end{pmatrix} \begin{pmatrix} E_0^H \\ E_0^V \end{pmatrix}, \tag{1}$$

where the first subscript in the scattering coefficient a_{HV} stands for the transmitted component and the second for receive.
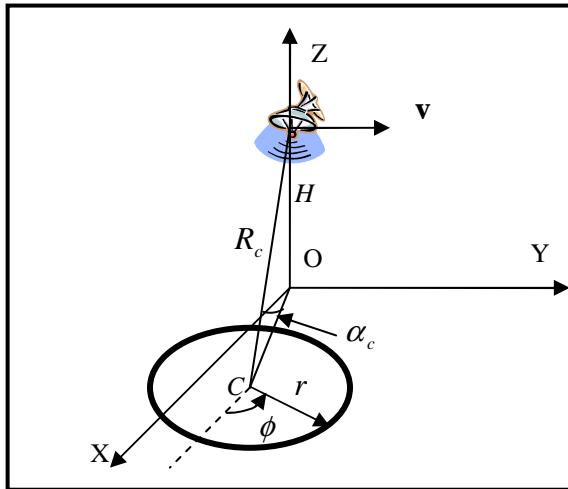

Figure 1. Scenario for the simulation (radar moves in parallel to the Y-axis).

If the diameter of the wire is small ($D \le \lambda/2$), the induced electric field direction is the same as the orientation of the wire segment, described by a unit vector v_w. If the unit polarization vectors for the incident field at the wire segment are, respectively, p^H and p^V, which are orthogonal to propagation path, we can express the scattering coefficients as:

$$a_{HH} = \left(p^H \cdot v_w\right)^2 \tag{2}$$

$$a_{HV} = a_{VH} = \left(p^H \cdot v_w\right)\left(p^V \cdot v_w\right) \tag{3}$$

$$a_{VV} = \left(p^V \cdot v_w\right)^2. \tag{4}$$

C. An Example

1) Radar System

The example system is an L-band airborne radar with bandwidth 250MHz. Table I lists the system and environment parameters used in this simulation.

TABLE I.   EXAMPLE SYSTEM PARAMETERS FOR SIMULATION.

Parameter	Value
Carrier Frequency	1250MHz
Bandwidth	250MHz
Compressed Pulse Width	0.004 μs
PRF	750Hz
Platform Altitude (H)	0.6km
Platform Velocity(V)	50m/s
Number of Pulses per CPI	1024
Transmit Power	Average: 1 W per channel
System Noise Temperature	500K
Slant Range of Test Cell (R)	1.2km
Background	Farmland
Antenna	4×2 Half-wavelength Dipoles with Ground plane. Aim to test cell

2) Dual-Linear Polarizations

Assume that the target is a conductive, wire-type circular object with radius r = 25m, located on the ground. The center of the circle is in broadside at the slant range of 1.2km.

Assume that the transmitter transmits H- and V-components equally. Two receive channels are connected to the H- and V-polarization antennas, and called H-channel and V-channel, respectively. The ground clutter is assumed to be isotropic.

A data cube including 301 range cells and 1024 pulses was simulated. Figure 2 shows the range-Doppler resolution cells around the target, where the target spreads over 25 Doppler bins and 73 range gates, and total 190 different range-Doppler resolution cells.
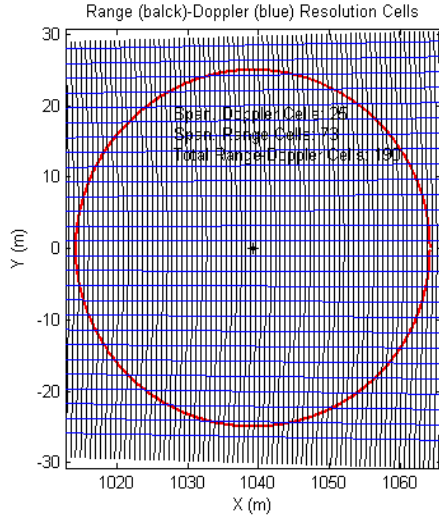
Figure 2. . The range-Doppler resolution cells around the circular wire.

Figure 3 shows the averaged power outputs including target, clutter and noise, in both receive channels as a function of range. Figure 4 shows the target and noise components only. As shown, the two channels have similar clutter power, but significantly different target signal power. The target has very strong returns at its two edge range cells where the circular wire produces specular reflection. Figure 5 shows the Range-Doppler spectrum in the H-channel. The target signal can only be seen in a few range-Doppler cells near the specular points. The target signals in most of the target-located range-Doppler cells are embedded in the ground clutter.
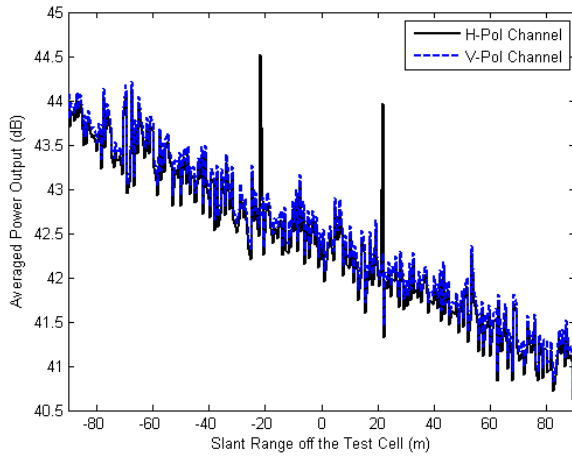

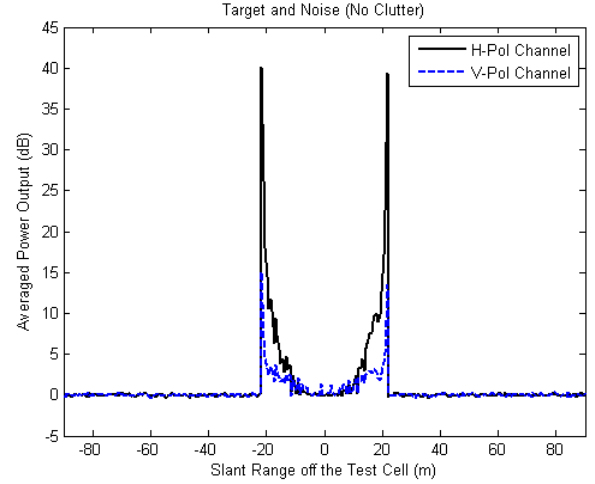Figure 3. Figure 1. Averaged power output as a function of range

Figure 4. Averaged target signal (and noise) power output as a function of range (no clutter).
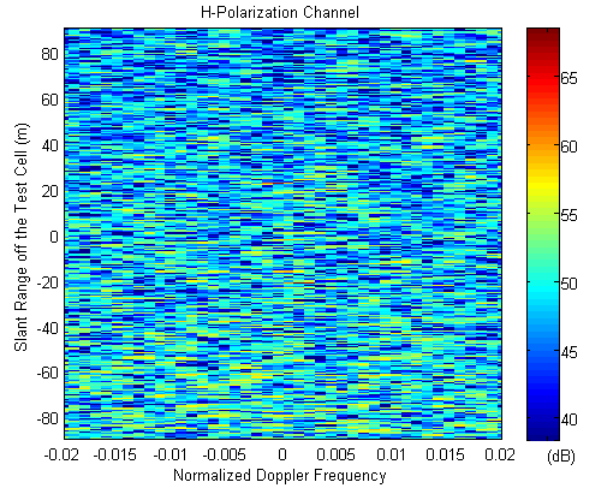

Figure 5. Range-Doppler output (H-Channel).

III. GIP DETECTION

Total 3072 pulses and 301 range cells were simulated. Assume that the number of pulses using in one CPI is 1024. Total 500 CPI's of range-pulse data are grouped from the simulated secondary data using a sliding window with 4 pulse shifting. A 1024-point FFT with 60dB Chebyshev window is applied to each CPI so that total 500 samples of training (range-Doppler) data were obtained. One CPI is used as the test data.

A. Mono-Polarization

Assume that the radar only has one polarization (H-polarization only). The template is a circular with a radius of r = 25m. Also assumed that there exist the secondary data including clutter and noise (no target), which are used to estimate the interference covariance matrix. Figure 6 depicts the range-azimuth GIP image. As seen, the range-azimuth GIP image looks like two rings with a junction point at the true

center of the circular target. The GIP image is also symmetrical in relation to the true center position of the circle. The radius of the circle can be obtained from the ring size in the image by converting the slant rage to the ground range. Figure 7 shows the results with V-polarization only. Because the target signal at V-channel is very weak (Figure 4), the GIP image of the target is not very clear.
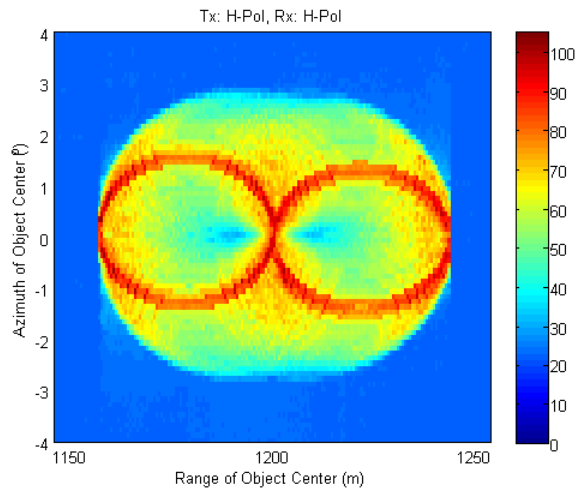

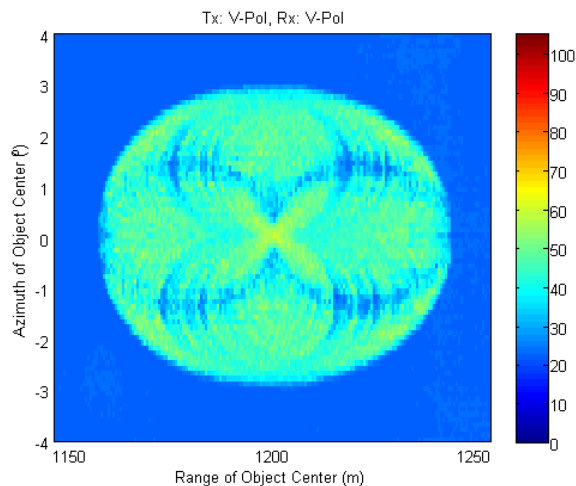Figure 6.   Range-azimuth GIP (H-pol only).

Figure 7.   Range-azimuth GIP (V-pol only).

B. Dual Polarization

In the above mono-polarization examples, the target-free secondary data are required. We may use the data acquired from different places, known target-free. However, the clutter background may be significantly different from the place under test. Therefore, the clutter may not be cancelled well using the estimated covariance matrix.

In a dual polarization system, both channels received the signal from the same location. As seen in the above example, the signal from a wire-type target in V-channel is much weaker than that in H-channel. Thus, we can use the data in one-channel as the data under test, and use the data from another channel as the secondary data.

Figure 8 shows an example, where the H-channel data including stronger target signal, clutter and noise are used for test, while V-channel data including weaker target signal, clutter and noise are used as the secondary data for the covariance matrix estimation. The range-azimuth GIP image can be clearly recognized as coming from a circular target. The target size can be estimated from the image.
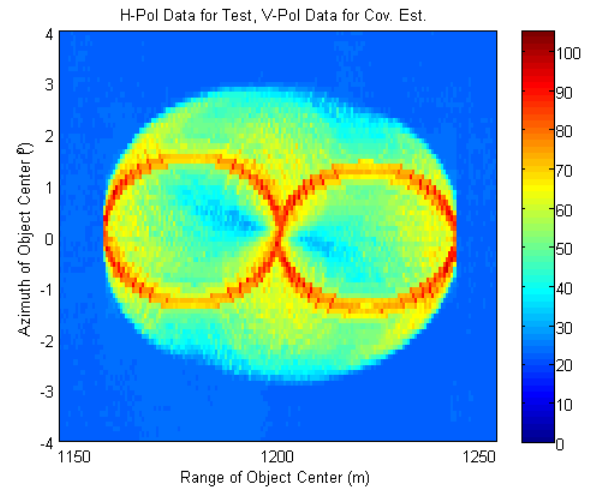

Figure 8.   Range-azimuth GIP (Dual-Pol transmit, H-Pol data for test, V-Pol data as secondary data).

IV.   SUMMARY

The GIP technique provides the capability of autonomous detection and parameter estimation of fixed targets in strong ground clutter. Multiple looks at an object during the radar's flyby will complete the image and improve parameter estimation. We have shown that the GIP approach can reveal the structure of doubly spread target and a dual polarization system can completely support the adaptive processing. Moreover, the polarizations can also be used to increase the *Mahalanobis distance* between the processed returns from the object of interest and other competing returns.

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